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Computational evaluation of building physics—The effect of building form and settled area, microclimate on pedestrian level comfort around buildings

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Abstract

Wind discomfort and the dangers that the wind may lead can be harmful in terms of comfort conditions of both indoor and outdoor environment of the building/buildings to be constructed or just completed. The wind effects on a site can be divided in two as: mechanical wind effects and thermal wind effects. This study is specifically about mechanical wind stress and pedestrian wind comfort. Typically, the cause of frequent occurrences of strong wind at pedestrian area is primary related to the configuration of building structures and/or topography in the vicinity of the pedestrian area. Depending on the characteristics of the wind including magnitude, uniformity, ambient temperature, etc., the level of disturbance to users of pedestrian areas can be different. In this context, the regions where Necmettin Erbakan University (N.E.U.) temporary education buildings are located have a fairly intensive topography in terms of wind. Therefore, detailed analyses of the inside regions and the surrounding areas of education buildings in particular are performed in terms of microclimatic comfort and indoor energy recovery. Especially, the topography where the university campus temporary educational buildings are located has very high wind climate conditions comparing to the city of Konya, Turkey, climate conditions. In this study pedestrian level wind conditions around N.E.U. campus buildings and in urban areas and campus buildings settlements topography are analyzed by CFD FloEFD. The aim of the study is to analyze causes of wind nuisance in campus site area and around temporary education buildings, and compare and evaluate remedial measures. The results show that current campus settlement, around the buildings and amphi classes are seen to reach very discomforting levels in terms of in classroom comfort. Draft architectural campus temporary education buildings projects proposed by the author can improve on existing wind conditions where possible, and as a minimum, can not significantly degrade wind conditions especially when considering the safety criteria.

Keywords

building form and building settled area,
pedestrian level comfort,
microclimatic air movements,
wind effect,
wind flow around buildings,
FloEFD CFD

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1 Introduction

For the building physicists, the outdoor environment of the building is usually less interesting as compared to the climate events inside the buildings. Some of the fundamental purposes of building physics involve boundary conditions related to building interior climate and comfort studies, building envelope resistance and behavior about heat and humidity. In order to obtain comfort conditions for pedestrians around the building environment, it is essential to know the exterior microclimate parameter behaviour very well and to analyze them thoroughly. Within the scope of this information, it is important to check the form of the building or buildings as well as the campus design which will be created by the building community. The aim of the study is to analyze causes of wind nuisance in campus site area and around temporary

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education buildings in Necmettin Erbakan University, and compare and evaluate remedial measures. For this reason measurements and CFD simulations have been performed and compared to each other. Wind discomfort and the dangers that the wind may lead can be harmful in terms of comfort conditions of both indoor and outdoor environment of the building/buildings to be constructed or just completed. The extent of discomfort to pedestrian varies from inducing slightly unpleasant feeling to producing a falling down hazard. The wind effects on a site can be divided in two as: mechanical wind effects and thermal wind effects. This study is specifically about mechanical wind stress and pedestrian wind comfort.

Wind comfort and wind safety for pedestrians are important requirements in urban areas (Bottema 1993; Moonen et.al. 2012). In awareness of its significance, many urban authorities grant new building permits only after a wind comfort and wind safety assessment study reveals a sufficient degree of comfort and safety. Wind comfort assessment studies consist of statistical meteorological data in correlation with aerodynamic data, and comfort criteria. Aerodynamic data are to transform the statistical meteorological data from weather station into the location of interest at the building site, after which it is combined with a comfort criterion to judge local wind comfort. Aerodynamic data usually consist of two parts: terrain-related component and design-related component. The terrain-related component represents the statistics from the meteorological site on the change of wind to a reference location near the building area. The design-related component represents the statistics of the change in wind due to local urban design, i.e. the configuration of the buildings. It can be obtained by either wind-tunnel testing or numerical simulation with computational fluid dynamics (CFD). CFD offers some specific advantages over wind tunnel testing. Since simulations can be performed at full scale, it is not adversely affected by any scaling problems and similarity constraints. This may be important when flow at a wide range of relevant length scales, such as flow around facade details like balconies on a building that is part of a larger urban area, needs consideration as in this paper. CFD also provides all flow field data, i.e. information on the relevant parameters at every position in the model, while wind-tunnel measurements are generally performed only at a limited number of selected positions.

The use of CFD in wind comfort studies has received strong support from several international initiatives that focused on the establishment of general best practice guidelines (e.g. Franke et al. 2007; Tominaga et al. 2008a; Casey and Wintergerste 2000; Blocken and Gualtieri 2012). In the past, several CFD studies of pedestrian-level wind conditions around buildings and/or in complex urban environments have been performed (Bottema 1993; Stathopoulos 2006; Yoshie et al. 2007; Moonen and et al. 2012; Blocken et al. 2007a; Murakami 1990; Blocken et al. 2012). The majority of these studies were conducted with the 3D steady Reynolds-averaged Navier–Stokes (RANS) approach. Most previous studies on pedestrian-level wind conditions included validation by comparison of the CFD results with wind-tunnel measurements for the same building or urban configuration (Richards 2002; Stathopoulos 2006; Yoshie et al. 2007; Mochida and Lun 2008; Gadilhe et al. 1993; Stathopoulos and Baskaran 1996; Ferreira 2002; Westbury et al. 2002; Blocken et al. 2008).

A smaller number of earlier studies had provided a comparison with field measurements (Yoshie et al. 2007; Blocken et al. 2012; Blocken and Person 2009; Janssen et al. 2012). Other studies applied so-called sub-configuration validation which also is the approach held in this paper. Sub-configuration validation refers to performing validation for simpler generic building configurations that represent sub-configurations of the more complex urban configuration (Blocken and Carmeliet 2004; Blocken et al. 2004)

Building outdoor microclimate condition: The microclimatic parameters which create the comfort conditions at pedestrian level outside of the building can be thought as the environmental physical parameters which are affect the climate comfort and the process of energy savings. These are solar radiation, ambient air temperature, ambient humidity and wind. Some precautions need to be taken related to design parameters in order to obtain interior climate comfort conditions. In order for these precautions to be taken, it is essential for the exterior environmental values to be obtained and the data will need to be compiled. As a result, the real values for the exterior environment parameters such as solar radiation, ambient temperature, ambient humidity, and wind have to be obtained for the characteristics days and the periods. For any interior region which is surrounded by walls, in order to achieve climate comfort with minimum amount of additional energy systems, it is essential for the design parameters to have suitable values. In the building design for achieving good internal comfort conditions in the building, it is essential to not just focus on topics related to building envelope, but it is also essential to analyze conditions related to human comfort at the pedestrian level outside of the building and it is essential to incorporate all the microclimatic parameters as well during the design process.

The topographic properties which would be applied to the building being designed would definitely change the topographical content and the environment along with the comfort conditions at the interior level and at the pedestrian level. Especially if wind characteristic (which is one of the physical climate parameters) is not well known and if it is not properly applied to the design, then it can cause very dangerous environments and regions to be formed. Pollution caused by the mishandling of the wind speed, and wind direction can cause regions which are very dangerous.

Proper settlement to the topography where the buildings are located depends on the variation of the other parameters like building's form, openings on the size and the adaptation to the environment and also the relationship with the surrounding buildings and the right usage of the landscape elements. If these parameters are evaluated and applied correctly, suitable comfortable conditions may be created. In case these parameters are not evaluated correctly during the design and application process, unsuitable and uncomfortable environments can be created. Uncomfortable, inconvenient environment can appear as follows:

For the buildings:

(1) High wind speeds that can reach uncomfortable or even dangerous cases for pedestrians around the buildings.

(2) Low wind speeds that may cause unnecessary transport and the collection of traffic and industrial gases.

(3) Uncontrolled reflection of sun beams or shading in front of the building.

(4) View with varying visual pollution or blocked view.

(5) Variables that may create acoustic problems vs. high wind speed on the pedestrian level

The number of studies carried out on the pedestrian comfort level around the buildings has been increasing in recent years. The buildings surrounding areas have been questioned due to the adverse comfort and safety conditions that can occur at pedestrian-level. The wind action manifests itself at the pedestrian-level basically in two ways: either it can be felt as a wind speed which affects the rate of heat exchange between people and the environment; or as a force that comes from the sum of pressure field incident on human body (Bênia 2010). The wind flow has multiple effects, including heat transfer by convection, penetration of rain, the dilution of the pollutants, noise or dust removal. The most significant effects on pedestrian are the mechanical and thermodynamic effects. This article only addresses the mechanical effects, noting that according to Lopes et al. (2008) the threshold of thermal comfort corresponds to wind speeds around 4.50 m/s.

The pedestrian comfort depends on several parameters among which stand out, in addition to wind speed (and bursts critical speed), the local climate and the season, the environment temperature, rainfall, humidity, people activity on public environment, clothing and factors, such as, age and psychological state of each other. A preliminary evaluation of the wind behavior at the ground level and around buildings can avoid the appearance of excessive wind-speeds. In this context, both buildings demolition and construction may change the optimum conditions of the wind flow. When evaluating the discomfort associated with pedestrian-level wind, it is necessary to study the phenomena occurring at heights below 2 meters and the speed average obtained in the period between 10 minutes and 1 hour (Bottema 2000). In fact, according to Bottema (2000), pedestrian discomfort happens whenever the wind effects become so strong and frequent (periods less than 1 hour) that people who are feeling these effects act to avoid them.

The early comfort assessment methods applied outdoors have generally been adjusted from those originally conceived for indoors, and are based on the assumption that the conventional theory of thermal comfort developed for indoors can be generalized to outdoor settings without change. However, that approach has been proved to be wrong (Becker et al. 2003; Nikolopoulou et al. 2001; Spagnolo and Dear 2003). When outdoors, people expect different climatic conditions and usually dress differently, according to the prevailing weather conditions. In addition, people outdoors may be exposed to intense solar radiation and winds, which will change their response towards the environment greatly (Wu and Kriksic 2012; Stathopoulos and Baskaran 1996; Stathopoulos 2006) Owing to the range of experiences and expectations of people outdoors, it is hypothesized that the acceptable comfort range for outdoor spaces should be wider than that of the indoor context (Stathopoulos et al. 2004; Paterson and Apelt 1986; Fenton 2011).

Three parameters apply in defining thermal comfort for a person: (a) Heat balance of the body; (b) perspiration rate within comfort limits; (c) average skin temperature within comfort limits. It is not possible to satisfy these three conditions by keeping the ambient air temperature within a certain range only.

According to Fanger (1970), the interaction of six fundamental factors defines human thermal environment and sensation of comfort: (a) ambient air temperature (T_a); (b) radiant temperature (T_{mrt}): a change of 1 °C by a change of 1 °C in T_a; (c) wind speed: a change rate of 0.1 m/s for per 0.5 °C change in T_a (up to 1.5 °C); (d) humidity: 10% change in relative humidity per 0.3 °C change in T_a; (e) metabolic rate: an increase of 17.5 W (above resting level) is equivalent to an increase of 1 °C in T_a; (f) clothing insulation (clo): a change of 1 clo is equivalent to a T_a change of 5 °C at rest and 10 °C during exercise (Shapiro and Epstein 1984).

The approaching wind is partly directed over the building, partly around the vertical edges, but the largest part is deviated to the ground-level, where a standing vortex develops that subsequently wraps around the corners and joins the overall flow around the building at ground level (Blocken and Carmeliet 2004). The typical problem areas where high wind speed occurs are the standing vortex and the corner streams. Further upstream, a stagnation region with low wind speed is present. Downstream of the building, complex and strongly transient wind-velocity patterns develop, but these are generally associated with lower wind speed values and are of less concern (Blocken and Carmeliet 2004).

2 CFD simulations for the case study

2.1 Boundary conditions and solver settings

With the utilization of FloEFD software using the computational fluid dynamics (CFD) analysis method, when the annual averages from the III. climate region (according to TS 825) [*TS 825 defines that the rules of calculation of heating demand in buildings and gives the reference and permeable values for heating energy. This standard is an adoption of ISO 9164 and EN 832 without cooling energy demand regulations. Konya, Turkey, has a continental climate with cold, snowy winters and hot, dry summers. Summer temperatures average 30 °C (86 °F). The highest temperature recorded in Konya was 40.6 °C (105 °F) on 30 July 2000. Winters average −4.2 °C (24 °F). The lowest temperature recorded was −25.8 °C (−14 °F) on 25 January 1989. Due to Konya's high altitude and its dry summers, nightly temperatures in the summer months are cool*] and the heating and cooling degree-days region properties for Turkey are compared, then it is observed that according to Konya climate region (which has mild and cool climate and where the heating needs are higher than the cooling needs); in the light of the real meteorological data of the temporary education buildings in Necmettin Erbakan University campus the following concept are analyzed: pedestrian level comfort conditions indoor and around the building/buildings, comfort condition between the building layout plan suggested by the author (however unimplemented by the authorities) and the current finished design plans are analyzed. The design suggested (but unimplemented) to the education buildings: the changes by the suggested wall structure by adding outdoor flow into the buildings; and also how it affects the comfort conditions in an amphi determined indoor are considered. With this study, not only the outdoor flow conditions of full wall, wall with apertures and without a wall are discussed, but also the indoor conditions are analyzed depending on the comfort angle in the indoor regions.

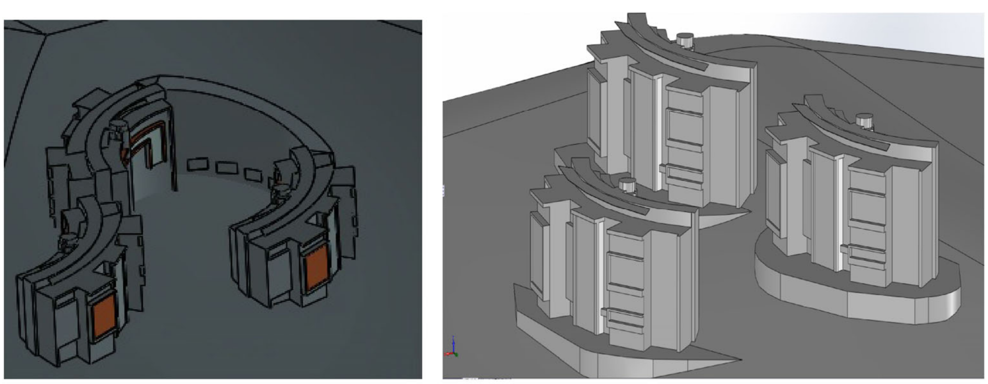
In the outdoor flow analysis of Necmettin Erbakan University campus temporary education buildings:

- Examinations of the existing building settlements with TOKI (The Housing Development Administration of Turkey) drawn sub-projects such as the architectural application projects, mechanical-installation project, and static project by university administration.
- Building settlement plan with close wall model which has been previously proposed and suggested by the project author.
- Building settlement plan with open wall model which has been previously proposed and suggested by the project author.
- Site plan model which is the settlement plan proposed by the project author, but currently applied in different settlement options are studied.

Pedestrian level comfort conditions analysis around the building/buildings have been conducted for the heating period in January 21 and for the cooling period in July 21 between 13.00–16.00–19.00 hours; airflow analysis occurred in pedestrian level heights is also conducted for the same days during 07.00–14.00–21.00 hours.

With the information obtained from the 2D architectural project and layout plans of the buildings, the solid model of the 3 buildings has been created. The 1.00 km × 1.00 km topography where the buildings are situated has been obtained from the Google Earth software (Fig. 1).

In the numerical analysis conducted, the finite element method has been used in the campus building models for the solution. The conservation equations for energy, mass and momentum (Favre- Averaged Navier–Stokes /FloEFD Computational Fluid Dynamics Software) have been solved.



(a) (b)

Fig. 1 Site placement orientation suggested but not applied within the light of current climatic and topographic conditions by the author and the current applied building placement: (a) the unimplemented site placement orientation with spans on wall between the buildings forming a yard formation suggested by the author architect within current topographic and climatic conditions; (b) site placement orientation of the currently applied buildings

The quality of the grid has an effect on the precision when the results are compared with the experimental values. Due to this reason, in order for the atmospheric boundary layer to form correctly, a denser grid has been used in the regions where there are rapid changes in the geometry, as well as in the regions which are closer to the surface. In the other regions, a coarser grid has been used compared to other regions described above.

Grid tuning, which is one of the features of the software, has been used twice during the analysis. This way, the grid has become denser in the required locations, causing the flow solution to converge in the continuous flow regime. It has been automatically applied at every 300 iterations as depending on the average pressure changes at the pre-determined surfaces on the buildings.

The design of buildings must account for wind loads, and these are affected by wind gradient. The respective gradient levels, usually assumed in the Building Codes, are 500 meters for cities, 400 meters for suburbs, and 300 m for flat open terrain (Foss 1978).

At the inlet of the domain, neutral atmospheric boundary layer inflow profiles of average wind speed U (m/s), turbulent kinetic energy k (m^2/s^2) and turbulence dissipation rate ε (m^2/s^3) are imposed. These profiles are based on the aerodynamic roughness length z_0 of the upstream terrain that is not included in the computational domain. In Eq. (1) and (2), κ is the von Karman constant (= 0.42). For z_0 = 0.25, 0.5, and 1 m, the inlet longitudinal turbulence intensity (I_u) ranges from 22%, 29% and 39% at pedestrian elevation (z = 1.75 m) to 3%, 5% and 8% at gradient elevation, respectively. The corresponding values of u^*_{ABL} are 0.54, 0.66, and 0.83 m/s for a reference wind speed of 5 m/s at a height of 10 m. The turbulent kinetic energy k is calculated from U and I_u using Eq. (3) assuming that the standard deviations of the turbulent fluctuations in the three directions are similar ($\sigma u = \sigma v = \sigma w$).

$$U(z) = \frac{u^*_{ABL}}{\kappa}\ln\left(\frac{z+z_0}{z_0}\right) \tag{1}$$

$$\varepsilon(z) = \frac{U^{*3}_{ABL}}{\kappa(z+z_0)} \tag{2}$$

$$k(z) = 1.5(I_u(z)U(z))^2 \tag{3}$$

For the ground surface, the standard wall functions by Launder and Spalding (1974) with roughness modification by Cebeci and Bradshaw (1977) are used. The values of the roughness parameters, i.e. the sand-grain roughness height k_s (m) and the roughness constant C_s, are determined using their consistency relationship with the aerodynamic roughness length z_0 derived by Blocken et al. (2007a,b).

Standard wall functions are also used at the building surfaces, but with zero roughness height $k_s = 0$ ($C_s = 0.5$). Zero static pressure is applied at the outlet plane. Symmetry conditions, i.e. zero normal velocity and zero normal gradients of all variables, are applied at the top and lateral sides of the domain.

The solver settings are identical to those in the validation study reported in Section 3. The 3D steady RANS equations with the realizable k–ε turbulence model are solved for the 12 wind directions θ = 0–330° in 30° intervals. Convergence was achieved when the scaled residuals showed no further reduction with increasing number of iterations and when the residuals reached the following minimum values; x-, y- and z-momentum: 10^{-6}, k and ε: 10^{-5} and continuity: 10^{-4}.

One of the most important criteria in the outdoor aerodynamics analysis around the building is the correct modeling of the atmospheric boundary layer (Tominaga et al. 2008b). The wind boundary layer at open area regions has been defined with the equations below by using the Hellman approach for wind profile (Blocken and Carmeliet 2008; Blocken and Persoon 2009).

$$v_z = v_g \cdot \left(\frac{z}{z_g}\right)^{\frac{1}{\alpha}}, \quad 0 < z < z_g \tag{4}$$

v_z = speed of the wind at height z;
v_g = gradient wind speed at gradient height z_g;
α = exponential coefficient;
To calculate α, profile uses the inverted equation as
$\alpha = \log(v_2/v_1) / \log(h_2/h_1)$

If wind speed is known for a single height only, α must be estimated, which depends on various factors including roughness and terrain of the site. Some empirical values for temperate climates are as Table 1.

$$V_{mz} = V_{ref} \cdot \left(\frac{z}{10}\right)^{\frac{1}{0.20}} \tag{5}$$

where: z: the height where the wind velocity is calculated; V_{mz}: maximum velocity obtained; V_{ref}: the velocity at station measurement height (10 m); α = 0.2 open field surface, Hellman coefficient.

While the reference height is taken as 10 m, the prevailing wind velocity at this height is 2.1 m/s and the direction is westward. Another important point is that many of the analysis software conduct flow analysis for materials with a low roughness coefficient; and thus in the FloEFD software

Table 1 Some ecmirical α values

Site conditions	α
Open water	0.08–0.15
Flat terrain, open land cover	0.16–0.22
Complex terrain with mixed or continuous forest	0.25–0.40
Exposed ridgetops, open land cover	0.10–0.14
Sloping terrain with drainage flows	0.10–0.15

the roughness coefficient is defined as zero. Depending upon the region that the building is located at, the roughness coefficient must also be defined. Since it is an open region surface, the surface roughness is defined as 0.2 m.

- Prevailing wind; with the wind velocity input from 10 m height, is defined to the flow volume as a boundary condition with 2.1 m/s magnitude.
- For the winter season: January 21; summer season: July 21. Building site is selected with the latitude 37.8578° N and the longitude 32.46° E.
- Ambient temperature 30 °C, fully cloudless days.
- Human face emissivity value is 0.93; absorption value is 0.2.
- Building envelope structure physical properties (ρ = 500 kg/m^3, k = 0.18 W/(m·K), C_p = 840 J/(kg·K)).
- Heat production value for the residents in the amphitheatre is 70 W/m^2.
- All leaks inside the volume are neglected.
- The average humidity amount is assigned with the initial condition as 50% average inside and outside of the amphi.
- Solid model of the volume is prepared in 1/1 scale from the obtained site plan.
- For metabolic velocity and mechanical efficiency; 1.2 met (1met=58.2 W/m^2).
- For the clothing insulation and moisture permeability; 0.57 clo (1clo=0.155 (m^2·K)/W).
- Reference temperature 24 °C.
- Humidity ratio 50%.

3 Results and discussion

3.1 CFD modelling

The computational geometry and computational domain are constructed in accordance with the best practice guidelines by Franke et al. (2007) and Tominaga et al. (2008b). Around campus area of interest the domain consists of an upstream (5*H*), a downstream area (15*H*) according to best practice guidelines, where *H* is taken as the height of the highest campus building near the border of the explicitly modeled domain. The total height of the domain is about 5 times the height of the heights building. A high quality and high resolution computational grid is generated. Hexahedral cells are used for optimum grid quality and convergence properties. In accordance with best practice guidelines, pedestrian height (1.75 m) was located in the middle of the cells from the ground.

In terms of investigating the outdoor pedestrian level comfort of the concept building models which are not built according to the current seasonal and topographic conditions and the buildings currently made and the campus education buildings considered, completely open case, closed case and perforated wall case outdoor flow conditions are analyzed.

For both the classrooms and for outdoor flow analysis, the flow velocities in continuous flow regime have been minified and they have been initialized as an inlet boundary condition to the computational volume. Furthermore, by keeping the sun hours in consideration, the 10 hours of analysis has been defined with 150 seconds of intervals.

Heat transfer and outer flow analysis on flow considered stable in 10 hours' time periods is conducted by using freezing the flow feature of FloEFD software. With this feature, on a completely stationary flow, energy conservation equations is continued to be analyzed. Depending time, solid material temperatures, radiation temperatures, interior medium flow temperature and comfort parameters explained above on interior surface are derived.

3.2 Assessment of wind comfort and safety around campus buildings

The velocity stream lines around the building are studied using the CFD method. The results are presented for the mean wind speed, V_{mean}, at a pedestrian height of 1.75 m from ground level. In order to compare the pedestrian level comfort around buildings conditions, the meteorological data are obtained from the Republic of Turkey General Directorate of Meteorology. Entry of the meteorological data and geographic data pertaining to the climatic region of the building are made by the user. Meteorological data entered to FloEFD software is an index pertaining to Republic of Turkey General Directorate of Meteorology for the outdoors weather temperatures, direction and intensity of wind, intensity of the direct and common solar radiation, and sky cloudiness in the region. These data where average values are frequently encountered have been found out for the heating and cooling periods having examined the long term meteorological data (Table 2).

Campus building environmental conditions during the monitoring period of the field analysis and the weather conditions vary with time on different days of months.

3.3 Completely open courtyard case pedestrian level wind flow analysis of over wall openings-building settlement (Unimplemented Plan)

Flow effect in the prevailing wind direction covered by buildings in the proposed settlement configurations of the three buildings makes separation (marked zones) at the corner points of the building before getting close to the building settlement and transfers a velocity airflow which is low at the building entrance and decreases strength in courtyard section. In the main entrance and the gathering sections of the buildings, regions protected from the high velocity winds with 0.5–0.8 m/s are formed. However, since the openings

Table 2 The meteorological data for Konya (obtained from the Republic of Turkey General Directorate of Meteorology)

Climate data for Konya (1960–2012)													
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Record high °C (°F)	17.6 (63.7)	21.6 (70.9)	28.9 (84)	31.5 (88.7)	34.4 (93.9)	37.2 (99)	40.6 (105.1)	39.6 (103.3)	36.1 (97)	31.6 (88.9)	25.2 (77.4)	20.4 (68.7)	40.6 (105.1)
Average high °C (°F)	4.7 (40.5)	6.8 (44.2)	12.0 (53.6)	17.4 (63.3)	22.2 (72)	26.8 (80.2)	30.2 (86.4)	30.0 (86)	26.1 (79)	20.0 (68)	13.0 (55.4)	6.7 (44.1)	17.99 (64.39)
Daily mean °C (°F)	−0.2 (31.6)	1.2 (34.2)	5.7 (42.3)	11.0 (51.8)	15.7 (60.3)	20.2 (68.4)	23.6 (74.5)	23.0 (73.4)	18.6 (65.5)	12.5 (54.5)	6.1 (43)	1.8 (35.2)	11.6 (52.89)
Average low °C (°F)	−4.1 (24.6)	−3.3 (26.1)	0.0 (32)	4.5 (40.1)	8.6 (47.5)	12.9 (55.2)	16.2 (61.2)	15.7 (60.3)	11.2 (52.2)	6.1 (43)	0.8 (33.4)	−2.2 (28)	5.53 (41.97)
Record low °C (°F)	−25.8 (−14.4)	−26.5 (−15.7)	−15.8 (3.6)	−8.6 (16.5)	−1.2 (29.8)	3.2 (37.8)	7.5 (45.5)	6.6 (43.9)	1.2 (34.2)	−7.6 (18.3)	−20.0 (−4)	−22.4 (−8.3)	−26.5 (−15.7)
Average precipitation mm (inches)	35.3 (1.39)	28.2 (1.11)	27.1 (1.067)	34.0 (1.339)	43.6 (1.717)	23.2 (0.913)	6.9 (0.272)	5.6 (0.22)	11.2 (0.441)	31.3 (1.232)	33.1 (1.303)	44.8 (1.764)	324.3 (12.768)
Average rainy days	9.7	8.8	8.7	9.6	10.6	6.5	2.8	2.4	3.5	6.7	7.0	10.0	86.3
Average relative humidity (%)	76	72	62	55	53	48	41	39	47	58	70	78	58.3
Mean monthly sunshine hours	96.1	126	189.1	207	266.6	312	347.2	341	288	220.1	150	93	2,636.1

on the wall are completely open, high wind velocity values such as 3.1–3.5 m/s are observed in the region away from the building between the structures (Figs. 2–3).

When the flow view in the direction of the prevailing wind in the open wall model between the buildings (for the proposed by unapplied settlement plan) according to the current topography and microclimate conditions by the project author is examined, it is observed that especially in the protected region among the buildings, wind flow velocity is higher due to the gaps between the buildings (Fig. 4).

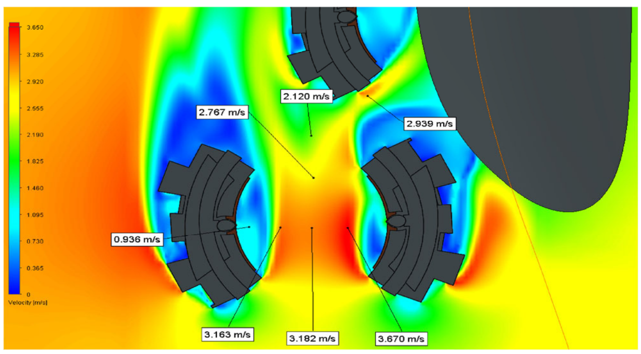


Fig. 2 Velocity distribution around the building in a plane parallel to 1.75 m floor of the airflow velocity in completely open aperture configurations over the wall in the walls proposed in the gaps among three buildings

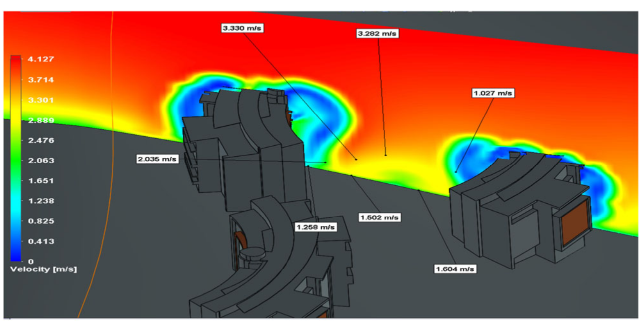


Fig. 3 Velocity distribution in a vertical section taken betwen the buildings

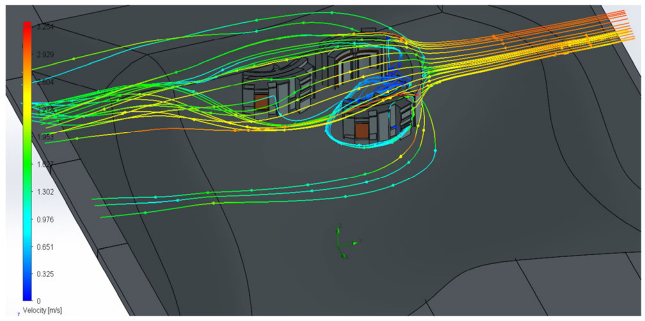


Fig. 4 Visualization of airflow among the buildings and around the buildings with flow strands

3.4 Completely closed courtyard pedestrian level wind flow analysis of the building settlement -over wall openings

When the flow analysis of the settlement option of the building layout is performed by closing with a wall rising equally parallel to the rise of the topography between two buildings, airflow velocities inside the courtyard are observed to drop significantly. Static air in the building entrance regions and inside the courtyard occurs between the buildings and because of this approach it provides relaxing and comfortable zones in terms of both wind strength and thermal comfort (Fig. 5). However, it may represent an uncomfortable environment partially because of decreasing thermal convection depending on the wind velocity in terms of thermal comfort in summer months.

Space among three buildings, another draft project suggested by the author, is closed and some openings are left in different regions in some places. These left opening is opened during the cooling season in any desired time in summer, so entrance of the wind flow into the courtyard is provided. In Fig. 6, outside the building, but inside the courtyard wind conditions in the configuration where the openings on the rising wall are completely closed are shown. In particular, in analyses performed for July 21 at 16:00, very serene calm region without winds is observed to be formed.

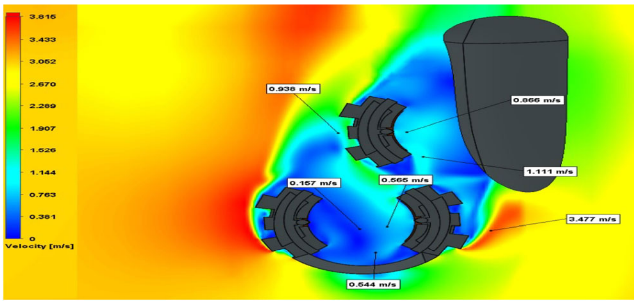


Fig. 5 Wind flow velocity distribution in the plane parallel to 1.75 m floor of the airflow velocity in the suggested building layout option completely closed with a rising wall

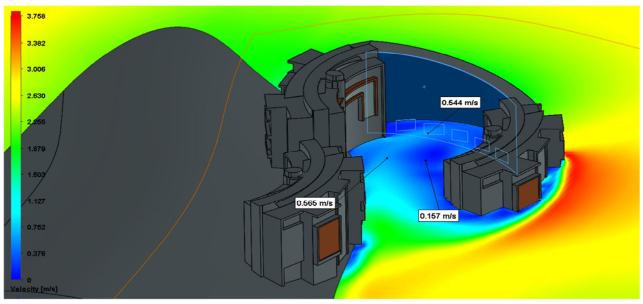


Fig. 6 Rising air distribution over the cross-section of the courtyard formed between the buildings

All inner courtyard and regions around the classroom areas have an average of 0.1 m/s wind velocity. In the open spaces of education buildings where no courtyard is formed, the wind velocity reaches to around 2.3 m/s (Fig. 6).

3.5 Layout settlement campus buildings analysis of current building application

Due to the layout of the buildings which is done without taking into consideration the current topographic microclimate conditions, the points of flow separation at the windward direction have come to the inner points of the courtyard.

Because of the settlement of the buildings, the point of the flow separation has come inside the courtyard. Velocity boundary condition given here is 2.1 m/s in 1.8 m height in the region among the buildings which increases the velocity level to 3.2 m/s from 2.1 m/s, since the separation point is transferred inside the courtyard. Therefore, current campus settlement buildings are seen to reach uncomfortable values in terms of the pedestrian level comfort around the building (Figs. 7–8). Airflow in the region outside of the structures formed with higher velocities occurs every time to a level at least 1.5–2 times in the interior courtyard section (stronger rather than 2.5 m/s). Since this increase occurs particularly in the region where building entrances and classroom amphitheater openings exist, they are seen to give serious discomfort in these regions (Figs. 7–8).

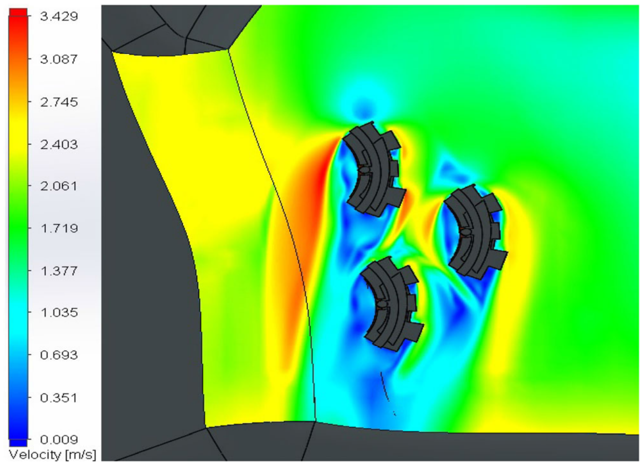


Fig. 7 Presentation of the airflow velocity in current situation in a plane parallel to 1.75 m floor

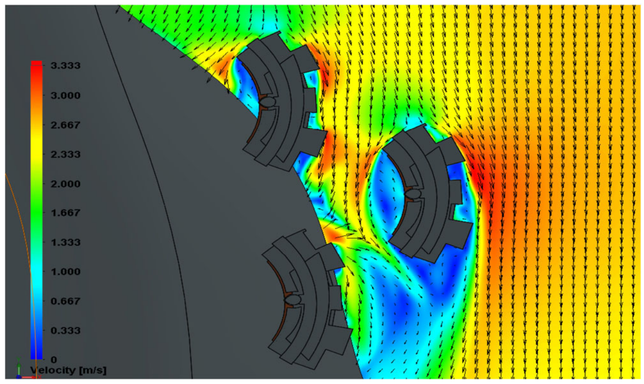


Fig. 8 Vectoral representation of the airflow velocity in the current situation in a plane parallel to a 1.75 m floor

4 Conclusions and recommendations

The total height of the domain is about 5 times the height of the heights building. A high quality and high resolution computational grid is generated containing about 1.2 million hexahedral control volumes. The CFD simulations are performed with 3D steady Reynolds-averaged Navier–Stokes equations and realizable k–ε model. In order to provide internal climatic conditions (climatic comfort conditions) with the help of current outdoor climatic conditions in the design of campus building settlement, a number of measures should be taken concerning the design parameters. In order to take these necessary steps, first the values of the outdoor climatic elements should be obtained and transformed to a usable format, in other words the climatic data should be compiled. Therefore, the values of the outdoor climatic elements such as solar radiation, outside air temperature, outside air humidity and wind of the region where the design takes place should be determined depending on the real atmospheric conditions. In order for the climatic comfort to be realized with minimum additional energy, design variables which are under control of the designer need to have appropriate values.

Especially since the topography where the university is located has a very high or very low outer temperature and wind velocity values; climatic comfort problems are observed to be formed. These are the discomfort problems occurring as a result of some reasons listed below;

- incorrect usage of the climatic parameters,
- incorrect direction of the buildings,
- faulty selection of thermal effects of the materials utilized in the buildings.

Because of the factors above, thermal discomfort is seen to occur in the current building settlement.

In the configuration in which collapsible openings on the walls proposed between the buildings in the campus building settlement architectural design by the author, thermal comfort values are extremely low since the wind flow inside the courtyard for July 21 reduces. However, the opposite case is observed when the values for January 21 are compared. July 21 outdoor comfort values of the configuration in which all openings over the wall are open are observed to be higher comparing to the configuration in which all openings are open.

The actual assessment of wind conditions at critical pedestrian locations must account for the probability of all wind directions that can occur based on the wind data from the appropriate campus education buildings. The pedestrian wind comfort level and safety exceedance are determined by the predicted wind speeds around current application of campus building placement.

Since the current application of campus building placement is built by ignoring the climatic values and dense wind conditions in the land, wind flow in both January 21 and July 21 analyses is observed to cause the wind to enter even inside the buildings at the points where the buildings are separating. Velocity boundary condition given here is 2.1 m/s in 5.00 m height in the areas between the buildings, and the transformation of the separation point inside the courtyard increases the velocity level from 2.1 to 3.5 m/s strength. These values are seen to reach discomforting values particularly in the regions where the building heights exceeds 5.00 m when they are evaluated according to Baufort comfort scale. Thus, current campus settlement, around the buildings and amphitheater are seen to reach very discomforting levels in terms of in classroom comfort. Draft architectural campus temporary education buildings projects proposed by the author can improve on existing wind conditions where possible, and as a minimum, can not significantly degrade wind conditions especially when considering the safety criteria.

- In configuration which is the suggested building layout option completely closed with a rising wall equally parallel to the rise of the topography between two buildings, airflow velocities inside the courtyard are observed to drop significantly. Static air in the building entrance regions and inside the courtyard occurs between the buildings. This configuration provides relaxing and comfortable zones in terms of both wind strength and thermal comfort.
- Space among three buildings, another draft project suggested by the author, is closed and some openings are left in different regions in some places. These left opening is opened during the cooling season in any desired time in summer, so entrance of the wind flow into the courtyard is provided. This configuration also provides relaxing and comfortable zones in terms of both wind strength and thermal comfort.
- Wind conditions along draft projects three building's south facade at grade are anticipated to be suitable for sitting during the summer and suitable for walking during the winter months. Because airflow velocities inside the courtyard are observed to drop significantly. Static air in the building entrance regions and inside the courtyard occurs between the buildings and because of this approach it provides relaxing and comfortable zones in terms of both wind strength and thermal comfort.
- The local pedestrian environment within the draft projects outdoor campus buildings common area along the courtyard's side of the building is expected to be moderately windy, resulting in conditions suitable for standing during the summer and autumn conditions, and suitable for walking during the spring and winter conditions. These wind conditions are considered to be acceptable for the intended uses of the space.
- But when we look in current building application configuration, due to the layout of the buildings which is done without taking into consideration the current topographic microclimate conditions, the points of flow separation at the windward direction have come to the inner points of the courtyard. This configuration increases the velocity level to 3.2 m/s from 2.1 m/s, since the separation point is transferred inside the courtyard. Airflow in the region outside of the structures formed with higher velocities occurs every time to a level at least 1.5–2 times in the interior courtyard section.
- Therefore, current campus settlement buildings are seen to reach uncomfortable values in terms of the pedestrian level comfort around the buildings.

Within the analysis, at the same time, in the survey carried out for both outdoor microclimatic comfort conditions and the indoor comfort conditions of the current buildings in which the options suggested by the author is not applied, and where instead the layout settlement suggested by TOKI (Housing Development Administration of Turkey) is applied, in the microclimatic measurements and as a result of CFD analysis works, applied projects are found to be quite weak and disadvantaged compared to the proposed ones.

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